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STUDY OF GROWTH IN RECENT AND FOSSIL INVERTEBRATE
EXOSKELETONS AND ITS RELATIONSHIP TO TIDAL CYCLES
IN THE EARTH-MOON SYSTEM

Semiannual Report on NASA Grant NGR 05-003-067

Covering period from
April 1970 through September 1970

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Principal Investigator: Professor W. B. N. Berry

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Introduction

Geophysicists have used data obtained from demonstrated and apparent growth rhythms observed in shells of fossil marine invertebrate animals to calculate the possible relationship of the earth and moon through prehistoric time and to postulate the possible origins of the earth-moon system (see Munk and MacDonald, 1960; Dicke, 1964; Runcorn, 1964, 1966; MacDonald, 1965; Lamar and Merrifield, 1966 a, b; O'Keefe, 1966; and Pannella, MacClintock, and Thompson, 1968). Orton (1926), Barker (1964, 1968), and Pannella and MacClintock (1968) indicated that many marine, intertidal-dwelling clams do secrete growth increments that are clustered between major grooves or bands that can be demonstrated to form annually. Orton showed that a prominent groove developed in the shells of many clams living in cool temperate waters as a result of very slow to no growth of the shell during cold water conditions that accompany the winter months. Pannella and MacClintock (1968) also demonstrated that fine growth increments were clustered between major bands, such as those formed annually in populations of *Mercenaria mercenaria* living off the New England coast.

Barker (1964), Berry and Barker (1968), and Pannella and MacClintock (1968) suggested that certain fine growth increments that may be observed clustered within the major, annually formed bands reflect environmental rhythmic changes such as tides and water temperature changes coincident with the seasons. The focus of attention in this project has been on the fine growth increments and clusters of them seen within the annually formed bands. The relationship of these shell growth increments to environmental phenomena has been sought and an attempt has been made to relate these features of the shells seen in living animals to similar features seen in the shells of fossils.

Many animals have been grown in the laboratory under a wide variety of environmental conditions. The laboratory results indicated that, in general, clams examined in the laboratory growth experiments secrete shell material in relation to their own innate (perhaps inherited) rhythms. No animals studied could be clearly demonstrated to have formed shell growth material in response to the artificial environmental rhythms to which they were subjected in the laboratory.

Many other intertidal-dwelling clams were examined in their natural habitats. Observations of shell calcification and growth of these clams indicated that most of these animals do secrete shell growth increments in relation to tidal phenomena. Several of them are also influenced by seasonal environmental phenomena, particularly seasonal temperature change. Among most of the intertidal-dwelling clams examined, a fine lamina appears to form in relation to each tide. The width of the lamina appears, in most species studied, to be about twice as wide in young animals (less than 3 years of age) than in those older than 3 years. The fine laminae are also wider in those animals living under conditions in which tidal activity is little-felt by the animal. Clams living at depths greater than those in which tidal activity is significant may not secrete growth increments in any apparent relationship to tidal activity; indeed, most clams living at depths beneath those of most conspicuous tidal activity secrete shell growth increments in response to environmental phenomena other than those connected with the tidal cycle. These observations thus indicate that, for use in analysis of the tidal cyclic phenomena in the geologic past, shells of fossil clams that, in greatest probability, lived within the intertidal interval should be examined.

Current aspect of the study

The main direction of the study in the past few months has been toward analysis of the data obtained from observation of shell growth in animals that were marked and allowed to grow in the natural habitat for periods of time up to 3 years. This aspect of the study has become increasingly important because variations seen among shells of living animals, even those of the same species collected at the same place, suggest that interpretations of shell growth increments among fossil

shells on which geophysical calculations are based may provide misleading and erroneous data unless great care is taken in selecting the fossil shells for examination. Furthermore, relatively little is known of day-to-day and month-to-month responses of living clams to their natural environments.

To more comprehensively examine the environmental influences on living clams, several hundred specimens from populations of *Chione undatella* living in Cholla Bay, Sonora, Mexico, and from Coyote Cove, Concepcion Bay, Baja California were studied closely at intervals of several weeks at a time for up to 3 years. Examination of several hundred specimens of *Chione undatella* from Sonora Bay that were marked and collected at intervals over a nearly 3-year period has shown that a prominent groove is formed in the shell of all members of this species during the winter. The animals secrete fine growth increments that are clustered, and the clusters are seen as ridges on the shell surface, during the spring, summer, and fall. The clusters number approximately fifteen fine growth increments to each ridge. The five increments are considered to have formed in relation to each tide, and each cluster of 15 is considered to reflect fortnightly tidal activity. To a degree, the seasons are reflected in the relative size of the ridges and grooves that are spaced between the annually formed grooves. Moderately sized fine growth increments and thus moderately spaced ridges develop during the spring and early summer. Widely spaced fine growth increments and the resultant widely spaced ridges form during the summer months. Very fine growth laminae and small ridges develop during the fall. These differences in the finest growth increments are most conspicuous in young animals. Older animals (those 4 years old and older) do not have such conspicuously different ridge sizes. Month-to-month sampling suggests that the actual season of growth of the shell becomes progressively less with increased age, with the growth season shortened to but a few months during the interval between late spring and early fall in old animals.

Individuals from a population of *Chione undatella* living in Coyote Cove off Concepcion Bay in Baja California were examined and compared with the individuals from Cholla Bay as a test of the effect of environmental changes on members of the same species living at the same time

but in different areas with somewhat different environments and slightly different seasonal changes. Seawater temperatures in Concepcion Bay are warmer during most of the year than are those in Cholla Bay. The temperature difference is most marked during the fall and winter months, during which time seawater temperatures in Cholla Bay are an average of 8 to 10 degrees centigrade colder than in Concepcion Bay. All of the Concepcion Bay specimens examined had a prominent groove that formed during the winter, just as in the Cholla Bay specimens. The size of the fine growth increments among young individuals and the number of ridges formed from clusters of these fine growth increments indicate that shell growth in the Concepcion Bay individuals continued longer into the fall and the hiatus in shell growth was shorter in duration than in the Cholla Bay individuals. Further, a markedly greater range in variation in size of the fine shell growth increments was noted among the Concepcion Bay individuals than that seen among the Cholla Bay individuals. The older animals in the Concepcion Bay population appeared to have spent longer periods without adding to their shells than did animals of the same age from Cholla Bay.

This comparative study thus indicates that shells of individuals of the same species and of the same age may vary widely, depending upon local environmental differences. Shell growth is clearly, in the case of the two populations of *Chione undatella* examined, reflective of the local environmental conditions, although the overall shell growth pattern is similar in that it reflects seasonal changes and tidal activity. Furthermore, older individuals of these species are not as responsive to environmental changes and, hence, the parts of the shells secreted by the mature animal are not accurate indicators of environmental rhythms.

In addition to these differences observed in closely studied populations of *Chione undatella*, specimens of *Mercenaria mercenaria* from a number of localities along the Atlantic Coast from the Carolinas northward into New England have been examined with possible latitudinal and water temperature differences in mind. Examination of the shells of this species indicates that those animals living in colder waters had very little shell growth during the winter months compared with those animals living in warmer waters. Further, the fine growth increments in the

animals living in warmer waters tended to be wider than those in the colder waters.

A number of shells from clams that lived in warm waters of the Indo-Pacific were also studied closely. Many of these species did exhibit some form of major groove on the shell which apparently developed annually. Species such as *Cucullaea labiata* have shells that appear to have been secreted continuously throughout the year, without a cessation of shell growth in the winter. The ideal time-keepers and reflectors of tidal activity, from the point of view of determining tidal activity from study of the shell growth increments, appear to be relatively rare among clams dwelling in temperate to cold waters but more common among warm water dwellers.

These results of a long-term study of shell growth among living animals suggest that, in any study of fossil clam shells to relate shell growth increments to tidal activity of the past, care must be taken to choose not only animals that lived in intertidal conditions but also those animals that lived in warm waters. Selection of animals that lived in cool waters and also close study of the shell growth increments in the mature parts of the shell of older animals may lead to erroneous conclusions. Any data put forward concerning tidal activity as deduced from a study of clam shell growth increments must be viewed with caution. Numbers of specimens need to be examined and shell growth increment counts handled statistically to obtain useful numbers that are not biased by variation in shell growth from individual to individual of the same age and by variation among animals of different ages. This aspect of the project has revealed how closely tied individual responses are, even among clams, to local environmental conditions and how closely shell structures may simply reflect what has happened to any individual during its life-time. These individual variations of shell structure among individuals of the same age from the same place thus suggest that numbers useful to geophysical investigations that are derived from clam shell growth elements must result from a large volume of data. Numbers used in geophysical calculations derived from a few individuals can easily, and probably will, lead to erroneous conclusions.

The future

In the future, more data will be amassed concerning the responses of the living animal to local environmental conditions. Some more data from study of fossil shells will be obtained, with particular attention to shells of animals from the Mesozoic. Shells from that part of the geologic column are perhaps most useful to any speculative considerations derived from clam shell growth studies because the Mesozoic is the time that has been suggested to be the interval during which original large continental plates broke up and drifted apart and that sea-floor spreading was most pronounced in its effect. Such effects should be reflected in tidal activity which should, in turn, have left its imprint on those clams that do secrete shell growth increments in response to tidal activity. Furthermore, warm water seas were apparently relatively widely spread during much of the Mesozoic.

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